WAVE-LENGTH MEASUREMENTS IN THE ARC AND SPARK SPECTRA OF HAFNIUM

By W. F. Meggers

ABSTRACT

Using the purest available samples of hafnium salts the arc and spark spectra characteristic of this element were photographed with concave-grating and quartz-prism spectrographs. Wave-length measurements were made on about 2,100 lines, but 609 of these were discarded as impurities, identified mainly as columbium, zirconium, and titanium. Nearly 1,500 lines remain to describe the hafnium spectra between the wave-length limits 2155.72 A in the ultra-violet and 9250.27 in the infra-red. In this investigation an attempt has been made to improve upon an earlier description of these spectra, (1) by extending observations to shorter and to longer waves, (2) by increasing the precision of the wave-length measurements to ± 0.01 A, and (3) by making a more critical differentiation between lines characterizing neutral atoms (Hf I) and those ascribable to ionized atoms (Hf II). Comparison of these results with the earlier measurements of zirconium spectra proves that hafnium was invariably present as an unrecognized impurity. The most sensitive Hf I and Hf II lines for spectrochemical identification are tentatively selected. The stronger Hf II lines are identified with faint Fraunhofer lines in the sun's spectrum.

CONTENTS

I. INTRODUCTION

In a letter addressed to Nature on January 20, 1923, D. Coster and G. v. Hevesy [1] announced the discovery of a chemical element having atomic No. 72. They proposed the name of "hafnium" (Hf) for this element because it was in Copenhagen (latin, Hafnia) that the discovery was made. This brilliant confirmation of the theoretical predictions of Prof. Niels Bohr was based on the evidence of Röntgen-ray spectra of zirconium minerals containing small amounts of hafnium, and was the first instance in which credit for the discovery of a new chemical element by spectroscopic methods was

[1] Coster and Hevesy, Nature, 111, p. 79; 1923.

transferred from optical spectra to the more accurately predictable Röntgen spectra. Shortly thereafter (March 10, 1923) H. N. Hansen and S. Werner [2] made the first announcement on the optical spectrum of hafnium. They published the wave lengths of 52 strong lines between 2500 A and 3500 A. This was followed by a list of 288 lines [3] covering the same interval, and then by 77 new lines [4] extending from 3505 A to 7240 A. A complete account of their researches on the optical spectrum of hafnium was published by Hansen and Werner [5] in "Communications to the Royal Academy of Denmark" of that year. The latter publication contained 807 lines ranging in wave length from 2253.98 A to 7240.9 A. The measurements were made relative to zirconium lines present as impurities, and a greater accuracy than about 0.05 A was not claimed. This list was reprinted in 1925 in a monograph by Prof. G. v. Hevesy [6] who also made a slight adjustment of the wave lengths. This appears to be, up to the present time, the only extensive list of hafnium lines, and no values laying claim to higher precision have been published. In March, 1926, Prof. H. Kayser [7] remarked in his Tabelle der Hauptlinien, "die Kenntnis von Hafnium scheint mir noch äusserst unvollkommen."

For several years the spectroscopy section of this bureau has had under investigation the structures of various spectra, especially to test, in successive periods of chemical elements, the alternation and displacement laws of spectroscopy and to determine the origin of the so-called *raies ultimes* which are the basis of spectrochemical analysis. Results for the first two long periods have already been published,[8] and some progress has been made with the next period,[9] in particular the elements lanthanum (57) and platinum (78). It is in this last-mentioned period that hafnium (72), the analogue of titanium and zirconium, finds its place, and it was believed that attempts to analyze its spectral structures should be preceded by a more careful description of the spectra. This was made possible through the kind generosity of Professors Bohr and Hevesy, who, in October, 1925, presented for this purpose two small samples of their hafnium salts. A detailed description of the hafnium arc and spark spectra derived from these samples is presented in this paper.

---

[2] Hansen and Werner, Nature, **111**, p. 322; 1923.

[3] Hansen and Werner, Nature, **112**, p. 618; 1923.

[4] Hansen and Werner, Nature, **112**, p. 900; 1923.

[5] Hansen and Werner, Kgl. Danske Vid Selskab. Math.-fysiske Medd., **V**, 8; 1923.

[6] Hevesy, Kgl. Danske Vid. Selskab. Math.-fysiske Medd., **VI**, 7; 1925.

[7] Kayser, Tabelle der Hauptlinien der Linienspektra aller Elemente, Julius Springer, Berlin, p. IV; 1926.

[8] Meggers, Kiess, and Walters, J. Opt. Soc. Am. and Rev. Sci. Inst., **9**, p. 355; 1924. Meggers and Kiess, ibid., **12**, p. 417; 1926.

[9] Meggers, J. Wash. Acad. Sci., **17**, p. 25; 1927. La I. Meggers, J. Opt. Soc. Am. and Rev. Sci. Inst., **14**, p. 191; 1927. La II. Laporte, Naturwissenschaften, **13**, p. 627; 1925. WI. Meggers and Laporte, Phys. Rev., **28**, p. 642; 1926. OsI, IrI, Pt I.

II. PROCEDURE

The two preparations of hafnium used are referred to as A and B. Most of the results were obtained with A, which the donors described as a very pure sample of about 0.3 g $HfOCl_2$ + aq. containing a small amount of zirconium. From this the water of crystallization was carefully removed by Mr. Knowles, of this bureau. The dry salt weighed only 0.19 g and there were some misgivings as to how long it would last in the arc. The actual experience with it was very satisfactory, the small sample just sufficing to make more than 20 well-exposed arc and spark spectrograms. Sample B consisted of 1.4 g HfO_2 containing about 17 per cent ZrO_2. It was used only for making the long exposures necessary to record the infra-red spectrum. Further details as to the "purity" of these preparations, especially of A, are presented under "results" of the spectrum measurements.

For the economical use of this material in producing the maximum number of spectrograms, and in order to avoid the troublesome bands of carbon and cyanogen which are always present when salts are burned in arcs with carbon or graphite electrodes the samples were fused on silver electrodes. The silver rods were 6 mm in diameter. A minute quantity of the hafnium salt was placed on the lower electrode of the arc for each exposure. When the salt vapors were carrying a large part of the current the characteristic green color of the silver arc was more or less effectively replaced by a bluish white flame. The color of the arc served thus as an indicator of the exposure being obtained of the hafnium; if only the green color of silver could be seen the arc was broken and another small dose of hafnium salt administered. A small amount of the hafnium preparation was thus fused with the silver electrodes each time an arc exposure was made, so that the same electrodes could be used for the production of very satisfactory spark spectra. Arc and spark spectra were thus alternately photographed with a comparison spectrum of the iron arc between. The reverse ends of these silver electrodes were used for photographing comparison spectra of silver arcs and sparks alongside the corresponding exposures to hafnium and silver, thus permitting easy recognition and elimination of the electrode spectra of silver, of its impurities, and of atmospheric lines.

The arc spectrum was produced with a 220-volt direct current of 4 amperes. Higher currents were avoided on account of the danger of melting the silver electrodes. Furthermore, it was thought desirable to operate with relatively low current so as to increase the enhancement of spark lines on passing from arc to spark.

The source of the spark spectra was a high-potential condensed discharge between the identical electrodes which had just previously served as the source of hafnium arc spectra. A 40,000-volt transformer consuming about a kilowatt was employed. Condensers of 0.006 μf capacity were connected in parallel with the spark, while the self-induction usually inserted for the suppression of the air

lines was intentionally omitted with the hope that this procedure would permit an improvement in the differentiation between arc and spark lines. Hansen and Werner [10] concluded from their work on hafnium spectra that "the difference between the arc and spark spectrum is not very marked." The explanation is probably to be found in their sources; in that their arc spectra were obtained from intense direct-current carbon arcs using currents as high as 25 amperes while the spark spectra were produced with a 40 cm induction coil, a battery of Leyden jars of about 25,000 cm capacity (0.0278 μf) and a relatively large self-induction of about 0.0005 henry, the combined effect of which would undoubtedly be to make the spectral characteristics of the spark approach those of their intense arc. When our results are compared it is seen that the relative intensities of hafnium lines are really very sensitive to the conditions of excitation, and if these be properly chosen they permit a satisfactory separation of the true arc lines (characteristic of neutral atoms) from the spark lines (ascribed to ionized atoms).

The concave-grating and quartz-prism spectrographs of the Bureau of Standards were employed in making the spectrograms. The gratings and their use in a parallel-light mounting have been described in earlier papers,[11] the quartz spectrograph is a large autocollimating instrument—Hilger's type E_1. With a single setting of the latter instrument the ultra-violet between 2150 A and 2600 A was recorded on a 10-inch plate, the scale ranging from 1.8 A per mm to 3.0 A per mm. With the Hilger instrument three spectrograms of the hafnium arc and spark were obtained on Eastman 33 plates. Fourteen spectrograms covering the interval 2300 A to 9300 A were obtained in the first order of our concave gratings; the Rowland grating with 20,000 lines per inch giving a scale of about 3.6 A per mm being used between 2300 A and 7000 A, while the region from 6500 A to 9300 A was photographed with the Anderson grating with 7,500 lines per inch and scale of 10.4 A per mm.

Long photographic plates of extra thin glass, 40 cm long by 6 cm wide, some of which were obtained in 1925 from Doctor Schleussner in Frankfurt a. M. and some in 1927 from the Eastman Kodak Co. were used. These were coated with high-speed emulsions and their thinness permitted their bending so that satisfactory focus could be obtained throughout their length. To render the plates sensitive to the green, yellow, red, and infra-red spectral regions, they were bathed in photosensitizing solutions of pinaverdol, pinacyanol, dicyanin, and neocyanin, respectively, by the usual methods.[12]

All spectrograms were measured on the large Gaertner measuring machine which has been described in connection with earlier investigations of the same character.[13] The plates were measured from

[10] Hansen and Werner, see p. 10 of reference No. 4.
[11] Meggers and Burns, B. S. Sci. Papers (441), **18**, p. 191; 1922.
[12] Walters and Davis, B. S. Sci. Papers (422), **17**, p. 353; 1921.
[13] Kiess and Meggers, B. S. Sci. Papers (372), **16**, p. 51; 1920.

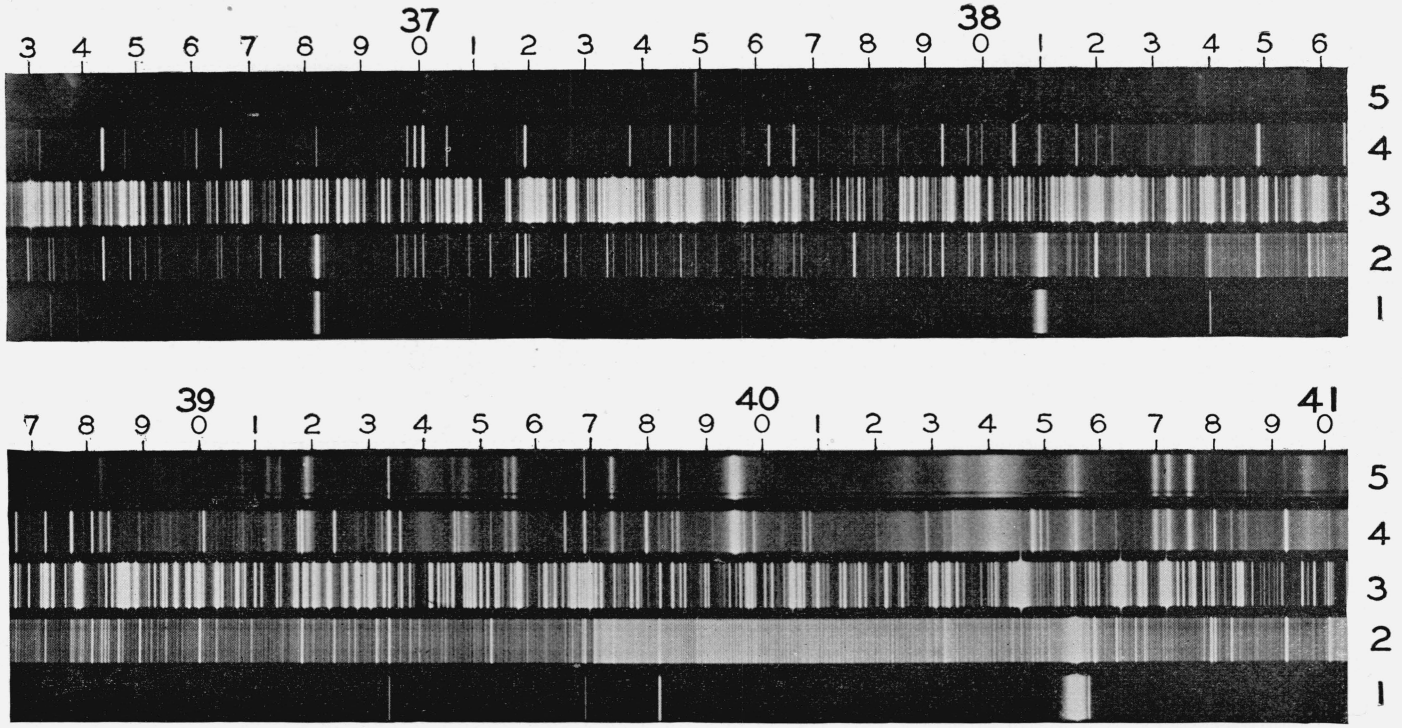

FIG. 1.—*Arc and spark spectra of hafnium and silver*

1, Arc spectrum of Ag; 2, arc spectrum of Ag+Hf; 3, arc spectrum of Fe; 4, spark spectrum of Ag+Hf; 5, spark spectrum of Ag. 3933, 3969, Ca^+; 3970, Hf band head; 3995, N^+; 3973, 4070, 4072, 4076, O^+

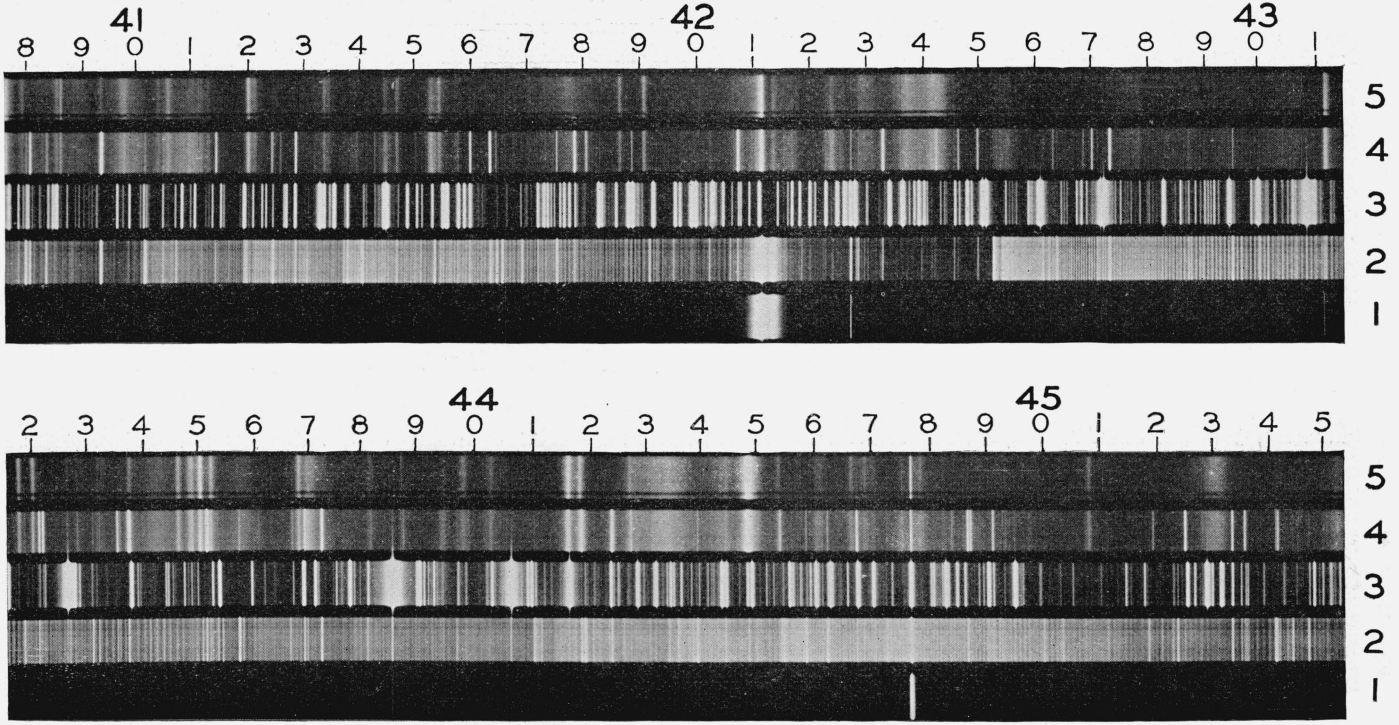

FIG. 2.—*Arc and spark spectra of hafnium and silver*

1, Arc spectrum of Ag; 2, arc spectrum of Ag+Hf; 3, arc spectrum of Fe; 4, spark spectrum of Ag+Hf; 5, spark spectrum of Ag. 4226, Ca; 4252, Hf band head; 4383, 4404, Fe; 4415, 4417, O^+; 4447, N^+

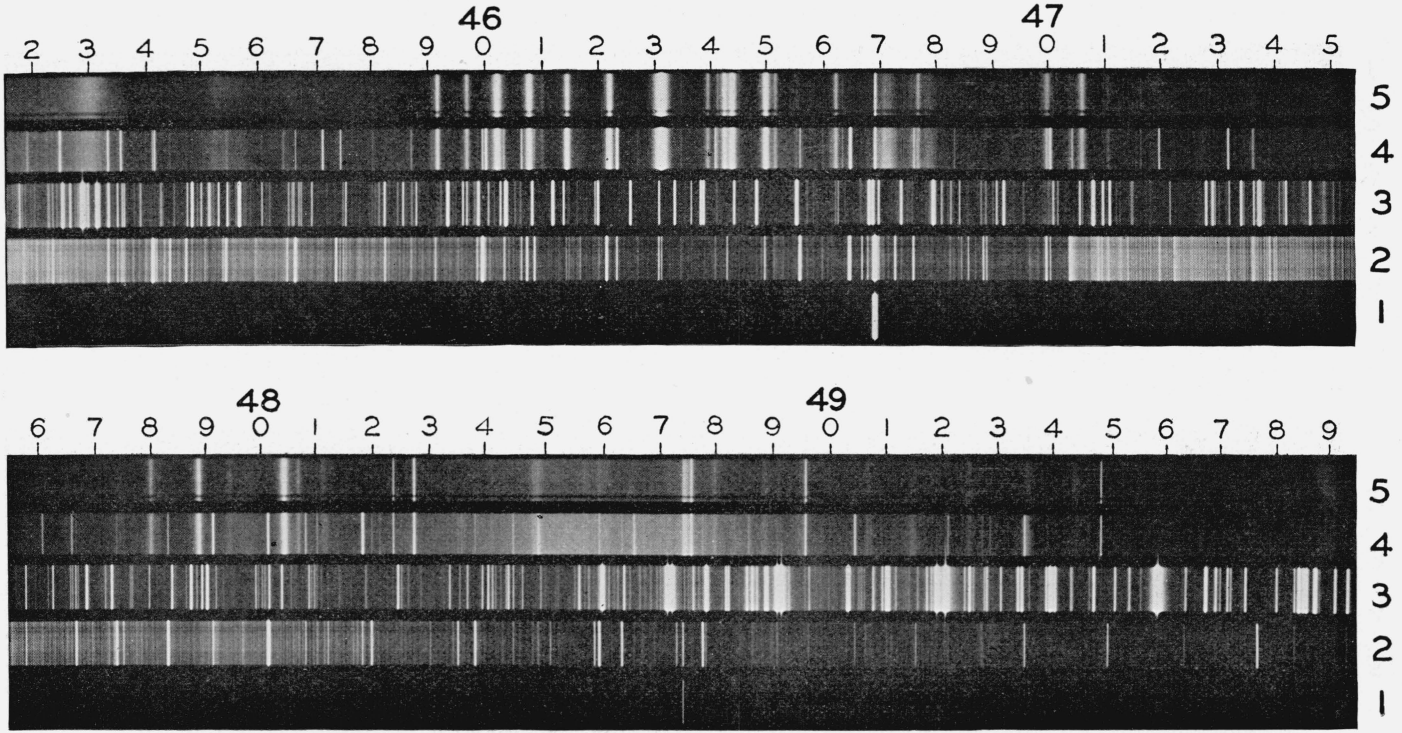

FIG. 3.—*Arc and spark spectra of hafnium and silver*

1, Arc spectrum of Ag; 2, arc spectrum of Ag+Hf; 3, arc spectrum of Fe; 4, spark spectrum of Ag+Hf; 5, spark spectrum of Ag. 4591, 4596, 4642, 4649, 4651, 4662, 4676, 4699, 4705, O^+; 4601, 4607, 4614, 4621, 4631, 4780, 4803, N^+; 4703, Hf band head

short to long waves and then in the opposite direction, settings on the spectral lines being recorded to 1 μ. So far as possible the wave lengths were determined by interpolation between the international secondary standards, but since these extend only from 6750 A to 3370 A the average values of other iron lines as compiled by Kayser and Konen [14] were used as standards down to 2324 A, beyond which the values for iron lines given by Schumacher [15] were selected as standards. The latter values are sadly in need of improvement. The first order spectra of wave lengths exceeding 6400 A were invariably measured relative to iron lines in the second order spectra which were photographed on removal of the Jena-red glass employed to absorb the second order hafnium spectra.

To illustrate the method of observing, and to exhibit some of the more striking features of the hafnium spectra, portions of the spectrograms are reproduced in Figures 1, 2, and 3.

III. RESULTS

When the wave-length measurements and computations of hafnium spectra were finally completed and compiled they totaled more than 2,100 lines ranging in wave from 2165 A to 9250 A. Forewarned that impurities were present, a systematic identification of these was begun by comparison with a list of *raies ultimes* of the chemical elements, the result of which was the detection of 17 different impurities. This does not include Ag, Cu, Na, K, Ca lines which originated with impurities in the silver electrodes because practically all of these were seen to be duplicated in the electrode comparison spectra and were, therefore, not measured. The zirconium lines showing in sample B (containing 17 per cent ZrO_2) contributed nothing to the list, because all of these lines were recognized from comparison spectra of zirconium metal. The complete wave-length list was next compared with the best available wave-length tables of the elements recognized as impurities, and all lines which could be ascribed with more or less certainty to the contaminations were struck from the list. In this way 609 lines were eliminated, the itemized list being as follows:

Columbium	357	Calcium	5
Zirconium	109	Silicon	5
Titanium	50	Aluminum	4
Tantalum	18	Magnesium	3
Iron	16	Rhodium	3
Tin	14	Lead	2
Copper	12	Barium	2
Manganese	10	Lanthanum	1
Palladium	7		

[14] Kayser and Konen, Handbuch der Spectroscopie, **VII**; 1924.
[15] Schumacher, Zeitschr. Wiss. Phot., **19**, p. 149; 1919.

As a further check on the elimination of lines due to impurities, my complete list of wave lengths was compared with Professor Kayser's Tabelle der Hauptlinien der Linien-spektra aller Elemente. This comparison disclosed a small number of additional coincidences with lines of other elements, such as cobalt, ruthenium, vanadium, molybdenum, and certain rare earth elements. Since each of these possesses a great abundance of lines, a considerable number of accidental coincidences may be expected, but no physical significance can be ascribed to them when the strongest and most sensitive lines are totally absent.

After eliminating all lines which could reasonably be ascribed to impurities, and a small number of faint lines resting on a single observation, the original list shrunk from 2,100 to slightly less than 1,500 lines. These are described in Table 1, where my wave lengths and intensities appear in the first and second columns, respectively. Each value is based upon at least two different spectrograms; about half of them depend on three observations, and many lines which appeared on overlapping spectrograms were measured on five plates. The probable errors of the mean of the latter are usually much less than 0.01 A, and it is believed that most of the values based on two or three observations are correct within 0.01 or 0.02 A. This is supported by the agreement of the impurity lines with the accurately measured wave lengths in spectra of the contaminating elements. Further evidence on the precision of these hafnium wave lengths will be deduced from Table 2 where some of my values are compared with accurate measurements of hafnium lines as unrecognized impurities in zirconium spectra.

My intensities are estimated on a scale of 1 to 100 so that the strong lines might stand out prominently and differences between the arc and spark might be more obvious. Unfortunately, the intensities of the spark exposure were not comparable with the arc for wave lengths greater than 6000 A. Beyond this point the intensities are mainly based on arc exposures made with the arc electrodes imaged on the spectrograph slit. Since the spectrograph is stigmatic the intensities of the lines in the center of the arc may be compared with those near the electrodes. Most of the lines are only slightly stronger near the poles than in the middle of the arc, but certain of them are very considerably enhanced, or make their appearance only at the cathode. Since the potential gradient in the arc is greatest near this electrode the conditions are here most favorable for the excitation of higher stage arc lines or of true spark lines. For lines between 6000 A and 7600 A, apart from those observed only at the pole of the arc, there is reason to believe that those which have intensity at least four times greater at the electrode than at the arc center may safely be assumed to be spark lines. It is a common

experience that the easily excited fundamental lines of neutral and of ionized atoms appear with great intensity in either arc or spark sources, but for the majority of the lines in Table 1 there is little or no doubt as to their correlation with Hf I and with Hf II spectra. Additional spectrograms with different exposures to the arc and spark, and stronger spark exposures in the red, would have made the differentiation still more positive. Attention is called to a group of lines between 2310 A and 2560 A which are abnormally enhanced in the spark. They must be ascribed either to Hf III or Hf IV spectra. It is noted also that these lines appear faintly or not at all in my arc and exhibit similar behavior in Hansen and Werner's spark, which is additional evidence that their spark was not especially well suited for the excitation of enhanced lines.

The wave lengths and intensities by Hansen and Werner are quoted in columns 3 and 4 of Table 1. In their original publication the wave lengths were expressed on the scale of Bachem's [16] zirconium wave lengths, since the zirconium lines appearing as impurities were regarded as convenient standards. Vahle,[17] who remeasured the zirconium arc spectrum with more care, found, on the average, somewhat larger values than Bachem, and explained the differences as errors in Bachem's scale, probably introduced by temperature shifts between his zirconium and iron exposures. The list of Hansen and Werner as reprinted by v. Hevesy is corrected to Vahle's scale and it is this corrected list which is quoted in Table 1. Although a greater accuracy than about 0.05 A was not claimed for their values, most of them appear to be well within this limit. The intensity estimates of Hansen and Werner were made on a scale of 1 to 6, which is perhaps too constricted a scale for a good gradation of intensities or differentiation of arc and spark lines. Band spectra from the carbon electrodes used by Hansen and Werner restricted the observation of hafnium lines in certain spectral regions, notably between 3750 A and 3890 A. On the other hand, the strongest silver lines from the electrodes used in securing my spectrograms appear to have obscured a few hafnium lines. For example, it appears that Hf lines at 2453 A, 2474 A, 3280 A, 3386 A, and 3682 A are covered or confused with silver lines on my plates. The greatest difficulty in describing the arc spectrum of hafnium arises from the band spectrum which probably originates with the oxides. Some of these bands are very strong and extremely complex over long spectral ranges. In many cases it is impossible to decide if faint lines belong to the Hf I or to the Hf O_2 spectrum.

In the last column of Table 1, some coincidences with other lines are noted. Certain of these may be real, at least in part, while others

[16] Bachem, Diss. Bonn; 1910.
[17] Vahle, Zeitschr. Wiss. Phot., 18, p. 84; 1918.

probably have no physical significance. The former class includes a considerable number of lines of impurities known to be present, but either the wave lengths or intensities are so discordant as to leave a suspicion that real hafnium lines also exist at or near these points in the spectrum. It was especially difficult to discard some of the approximate coincidences with columbium lines because the available wave lengths and intensities in the arc and spark spectra of columbium are not sufficiently reliable or extensive. Coincidences of the second kind, for example cobalt, ruthenium, molybdenum, vanadium, scandium, and yttrium are inclosed in parentheses since the probability is that they are purely accidental. A perfectly satisfactory description of hafnium spectra can not be made until much purer samples of hafnium salts become available. The ideal material for this purpose would be electrodes of spectroscopically pure hafnium metal and it is, perhaps, not unreasonable to hope for this in the future.

The unexplained symbols in Table 1 have the following significance:

h=hazy.
d=double.
c=complex.
n=band head.
l=shaded to long wave lengths.
p=part of band structure.
e=electrode line.
B. H.=band head.

TABLE 1.—*Arc and spark spectra of hafnium*

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
2155.72	--	5				
73.48	--	2				
74.32	--	4				
75.32	--	2				
78.49	--	2				
79.38	--	2				.4 Cu 4 4
83.48	--	10h				Hf III ?
89.59	--	1				.63 Cu 2 4
90.16	1	2				
90.36	--	4				
2195.41	--	15h				Hf III ?
2212.43	1	2				
13.53	--	20				Hf III ?
14.84	--	5				
21.86	--	1				
33.70	--	2				
34.60	1	20h				Hf III ?
35.45	--	2				
43.15	2	--				
54.01	4	6	3.98	2	4	
55.18	3	5	.11	1	3	
57.90	1	2				
58.70	1	2				
64.87	--	6h				Hf III ?
66.51	2	4	.51	1	3	
66.83	4	8	.81	2	4	
69.86	1	1				
73.14	3	6	.13	2	3	
77.15	10	10	.15	3	5	
83.00	1	--				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
83.56	--	5				
84.61	2	5	.57	1	2	
91.65	2	4	.64	1	2	
95.69	3	--				
97.76	--	1				(.8 La -- 7)
98.34	2	4	.34	--	2	
2298.77	1	1				
2302.08	1	2				
05.36	1	1				
10.21	--	10				Hf III ?
13.42	1	30	.43	--	1	Hf III ?
19.06	1	8	8.46	--	1	Hf III ?
21.13	4	3	.13	3	4½	
22.46	10	15	.44	4	5	
23.23	5	6	.23	3	4	
24.88	4	2	.86	3	4	
32.96	4	5	.95	2	3	
36.47	1	50	.44	--	2	Hf III ?
37.33	4	6	.33	3	4	
38.28	1	2				
39.67	--	?				Hf III ?
43.32	5	10	.32	4	4	
45.41	1	2				
47.45	8	25	.45	5	5	
51.22	10	30	.24	5	6	
53.04	2	--				
54.50	--	1				
55.49	--	20				Hf III ?
65.97	1	2	6.02	2	2	
71.40	1	2				
73.28	--	8				Hf III ?
77.57	--	20	.63	--	1	Hf III ?
80.29	5	10	.35	4	5	
81.00	2	6	.05	2	3	
83.55	1	30	.58	1	1	Hf III ?
93.21	3	5	.19	2	3	
93.36	5	10	.36	4	5	
2393.83	10	20	.81	4	5	.81Pb 5R 3R
2400.81	5	7	.80	4	4	
03.62	1	2	.61	1	2	(.6 Mo -- 4)
04.56	2	4	.57	2	3	
05.43	10	25	.43	4½	5½	
06.45	3	8	.43	3	4	
10.13	8	15	.13	5	6	
15.96	2	4				
17.23	--	1				
17.69	8	15	.67	5	6	.70 Sn 6R 8R
25.98	4	10	.95	4	4½	
28.99	2	5	.96	3	5	
33.56	5	15	.52	3	5	
34.76	2	5	.75	1	3	
41.05	1	2h	.04	1	2	
44.98	1	--				
47.25	10	20	.24	5	6	
49.44	5	10	.42	4	4½	
52.32	1	3	.28	2	3	
53.33	4	?Ag	.33	3	4½	
54.00	1	2	3.99	1	2	
54.60	--	1				
55.20	1	2	.18	1	2	
57.02	--	2h				
59.49	--	1	.43	--	2	
60.50	15	40	.47	6	6	
61.74	--	10				Hf III ?
63.97	--	5	.88	--	3	

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
64.19	20	75	.20	5	5½	
65.07	2	8	.03	3	3	
65.94	--	2				
66.84	--	2				
67.97	2	5				
69.18	8	20	.17	4½	6	
70.70	--	2				
73	?Ag	?Ag	.90	4	5	(.88 Ag 3 8)
78.57	1	5				.6 Ti -- 5
81.44	2	5	.41	2	3	
82.14	--	2				
82.67	2	--				
87.16	3	--				
90.89	--	1				
91.45	--	1				
94.44	1	3h	.38	--	2	
95.17	1	80	.15	1	3	Hf III ?
96.99	10	20	7.04	5	5	
2498.61	--	1				(.58 Ru 3 5)
2500.75	2	8	.76	3	4	
01.42	--	2				
02.66	3	--	.68	4	3	
10.39	--	2	.44	--	2	
12.68	15	30	.72	6	5	
13.02	25	50	.03	6	5	
15.16	--	30				Hf III ?
15.49	4	10	.51	4	4	
16.88	25	100	.89	6	6	
17.86	2	--	.88	1	2	(.87 Co 2R 2)
20.52	1	2h				(.53 Rh 2 10)
21.50	3	6	.50 (Cb)	3	4	
23.65	--	3				
31.20	10	25	.19	5	5	
32	--	--	.14	--	1	
32.97	2	3	.97	4	4	
34.34	--	5				
37.34	4	8	.34	5	5	
41.12	--	1				
41.86	--	2				
48.20	2	10	.20	4	4	
48	--	--	.54	1	2	
49	--	--	.00	--	1	
49.12	--	2	.14	--	2	
50.04	--	1				
50.72	--	1				
51.40	10	50	.40	5	6	.40 Cb 1 3
52.37	--	5				(.38 Sc II 3 8)
59.02	2	--				
59.20	5	15	.26	4	5	
60.32	--	1				(.28 Sc II 3 6)
60.75	--	10				Hf III ?
63.62	5	15	.65 (Mn)	4	5	(.64 Mn 3 5)
67.45	--	5				.5 Ti -- 8
70.72	2	5	.73	2	3	
71.68	25	75	.72	5	6	
72.96	1	3	.97	1	2	
73.92	8	40	.94	5	5	
74.30	--	2				
74.88	2	--	.93	1	2	(.88 Co 2 8)
76.84	7	20	.85	5	5	
78.15	5	15	.19	5	5	
82.51	5	15	.52	5	5	
82.87	--	2				
87.95	--	1				
91.33	3	5	.33	5	5	

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
95.61	--	4h	.61	1d	2	.6 Ag -- 3
2599.20	2	4	.18	1	2	
2602.68	3	--	.70	3	3	
02.86	2	--	.90	3	3	
03.50	2	1				
06.38	8	20	.42	5	5	
07.04	10	30	.06	5	5	
07.23	3	5	.31	2d	2	
08.47	5	1	.46	3	3	
08.63	2	--				(.6Zn I 8R 3)
09.29	--	2				(.3Mo -- 5)
09.95	3	--	10.01	3	2	
12.60	2	--	.60	3	2	
13.61	7	20	.63	4	5	
14.22	1	2	.31	1d	2	.20Pb 6R 5R
14.59	--	5h				.5Ag 2 6
16.61	2	--	.64	4	3	
20.97	--	1	.95	1	2	
22.75	5	20	.76	6	6	
26.97	1	4	.96	3	4	
35.79	1	5	.81	3	4	(.82Ru 4 3)
37.00	3	--	.00	4	3	
38.72	10	30	.72	6	6	
39.00	--	2h				
41.42	10	50	.43	6	6	
42.07	2	--				
42.76	3	--	.74	5	3	
47.31	8	30	.31	6	6	
49.16	--	4	.13	3	4	
50.33	--	2				
51.18	1	10				
52	--	--	.35	1	2	
52	--	--	.79	3	2	
57.50	2	4	.51	4	4	
57.85	2	6	.86	5	5	
61.89	4	12	.89	5	5	
65.98	2	6	.98	5	5	
68.28	2	--	.30	4	3	.26Cb 2 1
69.01	2	3	.02	5	4	
71.26	1	4	.22	3	4	
76.63	--	3	.60	2	3	
77.57	--	1	.59	2	3	
78.43	--	2	.38	1	2	
83.36	5	20	.41	5	6	
84.03	--	1				
85.23	1	5	.21	3	4	
87.22	--	3h				
88.35	1	--	.37	2	1	
96.18	2	--				
97.07	2	2	.09(Cb)	2	2	.07Cb 3 7
98.90	1	--				
2699.63	2	--				
2703.19	--	1	.17	1	2	
05.62	10	1	.64	6	5	
06.71	3	15	.72	6	5	
11.83	2	--				
12.43	5	10				.42Zr II --5
13	--	--	.50	½	1	(.50Mo 1 5)
13.84	3	--	.88	4	3	
18.51	2	5	.58	5	5	
18.57	5	--				
26.69	2	--				
27	--	--	.45	3	2	
29.10	2	--	.11	4	3	
30.71	2	--				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
30.84	4	--				
31.16	--	3	.13	1d	2	
33.00	--	3h				
35.12	--	1	.09	--	1	
37.82	3	--	.84	3	2	.83Fe 3 --
38.76	10	25	.77	5	6	
43.63	5	--	.64	4	3	
46.62	1	--				
51.81	5	15	.87	5	5	
53.61	--	8				
56.91	1	7	.95	3	4	
58.31	2	--				.31Ta 3 1
61.19	--	2				
61.62	8	1	.68	5	4	
62.69	2	--	.72	4	3	
64	--	--	.56	½	1	
66.96	4	--	.98	4	3	
70.42	2	5h	.47	4	4	
72.33	1	4	.36	3	4	
73.01	4	--	.01	3	3	
73.37	20	50	.42	6	6	
74.02	4	10	.07	5	4	
75.27	1	4	.28	4	3	
76.15	--	1				
79.36	8	1	.39	5	5	
83.68	3	--				
84	--	--	.50	½	1	
86.32	1	5	.33	3	4	
89.51	1	8				
2789.74	4	20				
2808.00	5	10	.02	5	5	
09	--	--	.61	1	1	.63Bi 8R 2
12	--	--	.33	2	2	
13.86	5	8	.88	4	4	
14.47	3	10	.48	4	4	
14.77	2	6	.81	3	3	
15.80	1	--				
16.07	--	3	.11	1	2	
17.68	5	--	.72	5	3	
18.93	3	--	.96	4d	3d	
19.75	5	--	.77	4	3	
20.23	20	50	.24 (Ti)	6	6	
22.67	10	25	.71	6	6	
29.33	2	5	.34	3	4	
33.29	7	1	.32	5	4	
34.12	3	--	.16	4	3	
41.49	2	--				
45.83	9	1	.81	5	5	
49.21	5	25	.20	5	5	
50.15	1	4	.13	3	3	
50.96	8	--	.94	4	3	
51.21	6	12	.24 (Ti)	5	4	
52.03	5	10				1.98 Zr II -- 6
56.96	--	1				
57.65	1	4	.67	4	4	
58.69	1	2	.71 (Mn)	1	2	
60.32	1	4	.34	1d	3	
60.56	5	--	.59	3	3	
61.01	10	20	.06 (Cb)	5	6	
61.69	15	30	.72	6	6	
63.33	3	--	.39	3	2	.32 Sn 8R 6R
64.58	--	1				
66.38	20	3	.38	6	6	
67.69	2	--	.79	1	2	
69.24	1	--				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
73.63	1	?	.66	3	2	.63	Rh	4	1
76.33	4	20	.37	5	5				
77.16	2	--							
79.11	1	4	.14	4	4				
85.47	1	4	.52	3	4				
87.13	6	1	.16	4	4				
87.54	3	--	.56 (Ti)	4	3				
89.01	--	1							
89.62	15	2	.65 (Mn)	5	5				
91.03	1	--							
92.55	2	--	.59	4	3				
94	--	--	.04	--	1				
94	--	--	.88	1	1				
98.26	25	3	.31	6	5				
2898.71	3	12	.79	5	4				
2904.42	20	3	.44	5	5				
04.50	--	3							
04.76	20	2	.84	5	5				
07.66	1	--							
09.91	4	5	.91(Ti)	5	5				
12	--	--	.79	1	1				
13.22	--	2	.19	½	1				
16.49	30	5	.55	6	5				
17.51	1	3							
18.58	12	2	.65	5	4				
19.59	10	20	.61	6	6				
24.61	5	1	.66(Zr)	3	3	.61	Zr	2	1
26.35	1	2	.46	1	3				
28.98	2	--							
29.63	8	10	.66	6	5				
29.90	8	1	.95	4	4				
35.37	1	--							
37.80	10	30							
40	--	--	.25	1	2				
40.77	25	4	.80	5	5				
43.70	1	--							
44.71	5	1	.73	4	4				
47.14	1	4	.16	3	4				
50.68	20	3	.72	5	5				
51.22	1	--							
51.90	1	--							
53.64	1	--							
54.21	15	2	.24	5	5				
58.02	7	1	.04	4	4				
60.83	1	5							
61.80	2	8	.82	4	4				
64.88	20	3	.86	5	5				
66.95	10	1							
67.24	2	10	.26(Ti)	3d	4	.22	Ti	8	2
67.86	1	--							
68.83	10	25	.87	6	5				
70.59	--	1h							
73.38	3	--	.42	--	3d				
74	--	--	.11(Cb)	2	3	.12	Cb	4	6
75	--	--	.38	1	1				
75.90	12	30	.91	5	6				
77.59	2	6	.61	4	4				
79.28	5	1	.26	5	4				
80.20	--	1							
80.82	15	2	.84	5	5				
82.73	5	1	.74	5	4				
84.06	2	--	.08	--	3				
90.83	--	2	.83	--	3				
2992.06	1	--	.01	--	1				
3000.10	6	10	.12	5	5				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
01.85	--	2h	.85	1	2				
05.56	15	3							
11.25	1	4	.23	2	3				
12.19	--	1							
12.90	15	25	.89	6	6				
15.29	1	--				.25	Cb	1	--
15.92	1	1				.93	Fe	3	1
16.78	30d?	2	.77	6	5				
16.93	--	2							
17.36	1	--							
18.32	15	2	.30	5	5				
20.54	20	3							
22.14	--	2h	.06	--	2				
24.61	2	--							
24.78	2	6	.73	--	4	.75	Cb	3	4
25.29	4	8	.34	--	4				
31.17	10	25	.16	5	6				
34.54	1	--	.56	2	1				
42.09	1	--							
46.03	2	5	.05	4	4				
49.30	2	--							
50.76	10	2	.76	5	4				
54.52	2	3	.50	4	3				
55.43	1	5	.47	4	3				
57.02	20	3	.04	5	5				
63.77	4	1				.82	Cb	2	3
64.68	2	8							
67.41	10	2	.39	6	5				
69.21	3	--	.18	3	3	.22	Ta	5	1
70.01	--	1							
70.47	1	--							
72.88	30	4	.94 (Ti)	6	5				
74.09	4	1	.11	3	3				
74.78	7	1	.81	4	4				
75.30	2	--				.25	Cb	2	2
75.94	2	--							
76.88	2	--	.88	2	3d				
80.63	3	20							
80.84	10	--	.77	6	6				
83.66	--	2h							
91.37	1	--							
91.78	--	2	.75	1	2				
92.25	2	5	.25	4	4				
96.76	6	1	.77	5	4				
3098.59	1	--							
3100.78	2	--	.77	--	1				
01.38	8	15	.42	6	6				
02.14	1	--							
02.34	1	--	.47	--	1	(.30	VII	10	10R)
03.69	2	--							
05.65	1	--							
06.01	2	1							
09.11	15	40	.14	6	6				
12.18	1	1							
14.80	1	--	.86	--	1				
16.94	1	4	.98	3	4				
19.97	4	--	.97	4	4				
22.55	1	--							
23.95	1	--	.90	1	1				
26.27	1	2	.31	2d	3				
26.65	1	--				.67	Cu	6	2
28.75	3	--	.75	3	3				
29.59	2	--							
31.81	12	2	.82	--	5				
33.10	--	1							

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
34.72	25	40	.77	6	6				
37.52	3	--	.55	3	3				
39.67	3	5	.69	3	4				
40.77	3	5	.78	3	4				
45.33	10	8	.33	5	6	.38	Cb	4	8
48.41	5	1	.46	4	4				
51.63	4	--	.65	4	3				
52.96	2	--							
56.68	10	1	.64	5	5				
59.83	10	1	.82	5	5				
61.55	1	--							
62.57	20	?	.59 (Ti)	5	6	.57	TiII	9	6
62.62	?	10							
65.73	2	--							
68.39	10	1							
72.94	15	2	.93	5	6				
74	--	--	.92	1	1				
76.86	10	20	.86	6	6				
78.43	2	--							
79.63	2	--	.48	1	2d				
81.02	5	--	.02	4	4				
81.13	4	--							
81.77	--	1h							
89.63	4	--	.69	4	4				
93.53	10	15	.50	5	5				
94.20	15	25	.20	6	6				
95.63	1	3	.62	2	2	(.61	Y II	8	10)
3196.92	5	--				.94	Fe	4	2
3200.00	3	7	.02 (Ti)	4	5				
02.16	1	2	.16	1	2				
03.68	1	4	.73	3	4				
06.11	7	1	.18	5	4				
06.77	1	2	.70	--	2				
10.97	4	1							
13.71	2	--							
17.30	5	4	.17	5	5				
18.20	--	3							
20.66	3	10	.61	4	5				
25.04	1	2				.03	Ni I	5R	2
27.00	1	2	6.97	2	3	(6.99	Co	6R	--)
27.87	2	--							
30.07	3	--	.10	3	2				
33.24	1	--							
33.80	1	1							
39.41	3	--							
43.00	1	3							
43.36	3	--	.40	4	2				
49.53	5	--	.52	4	3	.49	Cb	3	1
53.70	15	25	.70	6	6				
54.06	2	--				.05	Cb	3	6
54.86	2	--							
55.29	6	8	.30	5	6				
61.90	2	--							
62.47	3	--	.55	3	3				
65.29	2	--							
65.65	1	--				(.65	La II	6	4)
67.01	2	--				.03	Cb	2	1
67.17	3	--	.14	5	3				
73.66	1	2							
80	?Ag	?Ag	.02	5	5				
83.40	--	2	.42	5	3	.43	Cb	3	6
89.75	1	2	.73	1	1				
91.04	4	1	.05	4	3	.04	Cb	2	2
94.69	--	2h	.59	--	1				
3298.94	2	--	.96	3	2				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
3306.12	6	--							
09.20	3	--	.26	4	3d				
10.27	8	2	.25	5	4				
10.85	1	3	.92	1	3d				
12.87	15	3	.86	6	6				
14.03	--	1							
16.18	3	--							
17	--	--	.21	½	1	.19	Cu	5	2
17.99	5	6	.97 (Ti)	5	6	8.02	Ti II	5	5
18.28	1	--							
23.36	1	5h		½	2				
24.18	--	2	.18	½	2				
27.82	2h	--							
28.21	4	5	.18	5d	5				
31.87	2	--							
32.73	20	2	.74	6	6				
33.51	--	1h							
52.06	10	20	.03 (Ti)	6	6				
53.03	1	--							
56.78	3	--							
58.30	--	4h							
58.95	8	1	.92	5	3				
60.06	8	1	.08	4	3				
66.68	3	--	.71	4	2				
70.70	--	2h							
78.93	4	--	.88	4	3				
84.15	--	3	.17	1d	3d				
84.70	1	3	.67	5	4	.66	Cb	2	1
86	?Ag	?Ag	.10	4	4				
89.83	10	15	.78	5	5				
92.81	3	--							
94.99	3	8	5.00	3	4	.96	Cb	1	1
95.90	1	--							
97.26	4	--							
97.60	4	--	.50	4d	3d				
3399.80	30	40	.80	6	6				
3400.21	3	--							
02.51	3	--	.44 (Ti)	4	3				
07.13	2	--							
07.76	2	4	.77	4	4				
08.72	1	--				.66	Cb	3	4
10.18	5	15	.17 (Zr)	5	6				
12.38	2	--	.35	3	1				
13.74	1	3	.78	5	3				
17.35	5	--	.36	5	3	(.35	Ru	10R	3)
19.18	8	1	.19	5	4				
28.36	7	4	.39	5	5				
34.88	2	--				(.90	Rh	10R	10)
38.43	4	--							
40.88	2	--							
41.84	2	--	.87	3	2				
48.30	1	--							
52.31	2	--				.33	Cb	2	2
62.65	3	3	.68	4	4	.62	Cb	2	1
67.56	3	--	.61	3	2				
69.21	2	1							
72.38	20	2	.40	5	5				
75.85	--	2							
78.93	3	9				(.91	Rh	10R	10)
79.28	9	10	.22	6	6				
81.87	1	--							
84.71	2	--							
87.57	2	2	.57	½d	3				
95.75	5	5	.77 (Ti)	5	5				
95.93	1	3							

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
97.16	5	1				
97.49	15	2	.44	5	5	
3498.99	2	--				
3501.95	3	--				
03	--	--	.59	3	3	
05.23	20	40	.22	6	6	
06	--	--	.84	3	3	
11.88	1	3	.76	½	1d	
13.28	4	--	.28	3	3	
18.75	2	4	.74	3	3	
21.57	2	--	.57	2	2	(.57 CoI 5R 5)
23.02	15	1	2.99	5	5	
25.55	2	--				
26.87	1	--				(.85 CoI 9R 6)
30.87	2	--				
31.23	2	--	.21	2	2	
34	--	--	.49	3	2	
35.54	10	20	.51	5	5	
36.62	10	1	.59	4	4	
48.81	4	1	.80	3	3	
52.70	10	15	.67	5	6	
53.04	1	--				
54.00	3	--				
58.48	2	--				
61.65	20	25	.65	6	6	
64.31	3	--	.29	3d	3d	
65.32	2	--				
67.36	5	--	.37	3	4	
69.03	20	30	.04	5½	6	
79.91	2	--				
80.45	--	2				
83.27	2	--				
97.42	3	5	.43	4½	5	
97.50	3	--				
99.17	--	3h	.13	2	3	
3599.87	7	1	.88 (Zr)	4½	4	.80 Zr 3 6
3600.04	--	3h				
09.12	1	--				
15.05	3	--				
16.89	10	2	.87	5½	6	
17.70	2	--	.69	3	3	.66 Cb 2
20.04	2	--	19.99	3	3	
22.46	1	2	.43	2	3	
24.00	3	5				
27.83	2	--	.80	3	2	(.81 CoI 8R 4)
30.86	6	2	.85	4	4	
32.69	2	--	.68	2	2	
33.20	2	3	.15	--	3	
37.59	2	--	.60	3	3	
44.35	15	20	.31	6	6	
45	--	--	.80	1	1	
48.35	1	3	.33	3	3	
49.09	6	1	.08	4½	4½	
50.53	2	--	.49	3	3	
51.85	5	1	.80	4	4	(.83 ScII 10 10)
54.26	5nl	--	.22 B. H.?	3d	2d	
55.65	1+p	--				
56.64	--	2				
59.03	1	3	.00	2	3	
61.05	3	8	.04	4	4½	
61.74	--	1	.69	1	1	
64.65	3+p	--	.56	2	3	
65.36	4	10	.30	4½	5	
66.77	--	3d	.74	2	3	
68.20	2	--				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
72.28	8	2	.27	4	4				
75.74	9	2	.75	5	5				
78.06	--	3							
81.41	2	3	.37	3	3				
82.25	30?	?Ag	.24	6	6	.23	Fe	6	3
96.52	6	1	.50	4	4				
98.39	3	7	.34	2	2				
3699.73	7	15	.71	5	5				
3701.15	8	25	.14	5	6				
02.36	--	2							
04.92	2	--							
05.41	3	10	.40	4	4½				
07.36	2	--							
08	--	--	.87	2	2	(.83	Co	6	4)
17.80	15	3	.82	5	5				
18.83	--	2				.81	Zr	3	3
19.27	15	25	.30	6	6				
21.51	3	--				.50	Cb	2	1
22.65	--	2							
26.49	4	--	.50	3	3				
29.10	4	--							
33.78	10	2	.82	4	4				
37.88	4	10	.85	3	4				
39.02	3	1	.06	2	3				
41.96	--	2h							
44.98	3	10	.98	3	3				
46.80	9	2	.81	4	4				
47.48	3	4	.51	3	3				
53.21	4	1				.19	Cb	3	1
58.05	--	3							
62.51	2	20							
64.53	3	--							
66.12	1	--							
66.92	4	25							
68.25	5	1							
70.64	--	2h							
71.35	2	4							
72.86	--	1							
73.12	2	--				.18	Cb	2	
77.64	30	4	.74	5	5				
80.09	2	3							
82.43	2	--							
82.78	3	5							
85.46	25	3	.40	5	5				
87.38	2	--							
88.22	2nl?	--							
93.37	20	20	.35	5	5				
97.95	2	8							
98.67	3	--							
3799.52	--	2							
3800.39	15	5	.40	4	4				
04.16	2	--							
04.52	3	1							
06.07	4	25							
11.76	5	1							
16.08	2	--							
17.20	4	12	.05	2	3				
19.36	2	--							
19.93	--	2h							
20.74	15	3							
23.54	1	4h							
29.67	3	1				.67	Mn	3	3
30.01	7	2							
31.12	2d	--							
33.67	2	--							

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
38.37	1	2							
40.03	1d?	--							
49.17	10	2							
49.52	3	15							
50.34	1	--							
54.34	1+p?	--							
58.30	12	2				(.30	Co	6	3)
60.91	3	1							
64.75	2	10							
67.31	2	7							
72.54	4	8							
77.11	3	20							
79.26	1d?	--							
80.81	12	10	.79	3	3				
82.24	--	2h				.3	L	--	2
82.52	3	--							
83.13	2	--							
83.77	3	6							
85.67	2	--				.72	Cb	4	3
89.24	5	--							
89.33	4	--	.32	3	4				
92.49	2	--	.46	2	3				
95.	--	--	.63	2	1	.66	FeI	5	3
96.77	1+p	--							
3899.93	12	2	.93	4	5				
3900.66	1	10				.68	AlII	--	10
02	--	--	.91 (Fe)	4d	4	.95	FeI	7	5
06.91	2	--	.88	3	3				
09.18	3	--	.19	3	3d				
12	--	--	.51	1d	1				
17.47	2	6	.43	4	4				
18.10	15	10	.07	6	6				
23.91	6	10	.91	5	5				
26.45	3	1	.41	3	3	.46	Mn	3	4
27.58	4	1	.58	2	4				
29.24	1	2				.30	Cb	3	1
31.36	8	2	.34	3	4				
31.75	2+p	--	.79	2	2				
32.40	2	3							
35.64	3	6	.68	3	3				
38	--	--	.41	1d	2				
39.04	3	--	.01	3	3				
41	--	--	.18	1	1				
43.06	2	--							
45.37	--	5h	.32	2	2				
46.03	--	3h							
48.09	1p?	--							
49.48	1p?	--	.48	1	2				
50.79	3	1	.77	3	4				
51.81	15	2	.81	5	5				
64.95	3	7	.96	3	4				
67.25	1	--							
68.01	4	1	.04	2	2				
70.06	10nl	--	.10 B. H.	4	3				
75.15	--	2							
79.40	1	12	.36	3	4				
84.03	1	4	.03	3	4				
84.85	--	3				(.86	Ru	8	4)
88.23	1	--				.15	Cb	2	2
96.80	1	3	.78	2	3				
3998.50	1	4							
4002.50	2p?	--							
03	--	--	.78	2	2				
07.36	1p?	6	.36	2	3				
08.47	--	4	.46	2	3				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
09.78	2p?	--							
11	--	--	.50	2	2d				
11.94	1p?	--							
14.21	1p?	--							
20.25	2	2	.28	3	3				
22.84	2p?	--							
29.16	3	4	.19	3	3				
32.27	4	1	.29	4	4				
33.88	--	3	.88	1	2d				
44.38	3	1	.39	3	3				
46.75	1p?	--							
47.96	2	15	.98	3	4				
49.44	2	6	.45	3	3				
49.74	2	--	.76	1	1	.75	Cb	2	1
50.68	1	3	.63	3	3d				
50.88	2	--	.91	3	3				
53.25	1	--							
53.64	1	--							
57.42	2	--	46	3	2				
62.84	15	2	.86	4½	5				
64	--	--	.79	2	2				
66.23	8	1	.21	4	4				
67.84	5	1	.82	2	3				
80.44	10	10	.46	5	5				
83.36	10	2	.35	4	4				
87.96	1	--							
93.17	40	25	.18	6	6				
95.50	1	--				(.49	V	7	5)
4098.00	1p?	--							
[1] 4100.93	20ml	2				.99	Cb	30	10
04.23	3	1	.26	2	3				
06.56	4	1							
13.58	4	6	.54	4	4½				
15.89	1p?	--							
18.60	3	1							
18.91	2	--							
23.51	--	5							
25.10	--	3							
27.78	4	12	.76	4½	5				
36.38	2dp?	--	.37	2d	3d				
38.68	--	2							
41.83	--	3							
45.76	3	1	.76	3	4	(.76	Ru	6	4)
50.16	1p?	--							
51.49	1p?	--							
54.12	2p?	--							
56.12	2	1							
56.74	--	2							
58.90	2	10	.88	3	4				
62.40	4	15	.35	4	4				
62.68	3	--							
63.42	--	2							
70.41	2	1							
70.90	3	1							
74.33	30	3	.33	4½	5	.35	Cb	2	1
75.78	1p?	--							
77.50	3	15	.48	3	4	(.52	Y	10	10)
79.56	--	6							
87.67	2p?	4							
88.23	3	--							
4193.12	2p?	--							
4201.52	5	1				.54	Cb	4	2
06.57	5	20	.56	4½	5½				
09.71	5	2	.71	3	3				
21.75	1	--							

[1] Hf band head coincident with Cb impurity line.

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
28.08	7	1	.03	3	3				
31.19	1	--							
32.46	6	20	.39	4½	6				
45.15	5	1							
45.83	3	6	.84	3	4				
49.33	5	9	.32	4½	4½				
52.05	25nl	--	.02 B. H.	4	4				
53.59	5nl?	--							
60.96	4	2	1.02	3	4				
62.72	1	3	.72	3	3				
63.41	7	2	.42	4	4				
68.10	--	3							
69.66	1	6	.68	4	4				
70.59	2	1							
72.84	7	15	.84	4½	5				
83.45	2p?	--							
84.73	2p?	--							
94.77	20	3				0.79	Zr	6	2
4296.41	4	--	.42	3	3				
4303.60	3p?	1	.61	3	3	(.61	Nd	10	10)
04.41	3p?	1							
18.13	8	2	.17	4	4				
20.67	6	10	.67	4½	5				
21.36	1p?	10							
22	--	--	.67	1	2				
26.24	3d?	--							
30.27	8	2	.32	4½	4½				
34.64	3	8	.65	3	4½				
35.13	2	1	.15	2	3				
36.65	10	40	.71	5	6				
49.73	4	--	.78	3	3				
50.50	8	25	.53	4	6				
51.15	3	--							
52.56	3	--	.60	3	3				
53.32	3	--	.38	3	3d				
56.29	25	3	.33	5	6				
56.98	3	--							
65.37	4	--	.38	3	3				
67.89	8	6	.92	4	5				
79.13	3d	--	.19	2	2d				
85.52	--	2	.47	1	2				
90.70	1+p	--							
91.26	1	--							
92.69	2	--				.73	Cb	3	
4395.01	3c	--							
4408.82	6nl	--	.86	3	3				
15	--	--	.06	--	2				
16	--	--	.15	2	2				
17.35	8	10	.35 (Ti)	4½	6				
17.90	8	1	.86	3	4				
18.25	4	--							
22.24	2	--	.25	2	2				
22.75	6	30	.71	4	5				
30.63	1	--	.57	1	1	.62	Fe	4	--
32.93	2d	--	.95	1	2d				
34.52	3c	--							
38.02	10	2	.04 (Zr)	4	4				
43.07	4	2							
52.70	--	5							
52.97	4	--	.96	3	3				
57.35	15	2				(.36	Mo	7	3)
61.17	12	2							
66.38	3	8	.39	3	3				
73	--	--	.05	1	--				
83.29	--	2							

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
86.12	6	8	.15	4½	4½				
86.64	--	6							
90.59	1	6	.61	2	3				
4499.65	4	1	.65	2	3				
4518.30	5	1	.31	3	3				
19.01	--	4							
20.59	4	--	.60	2	3				
24.72	2	8	.66	--	3	.74	Sn	6	10
33.18	12	6	.15 (Ti)	5	5				
35.36	2	7	.32	2	3				
39.74	1	1							
40.92	20	3	.88	4	4				
41.29	4	6	.28	1	3				
41.70	4	--	.73	1	1				
43.01	2	--	.00	2	2				
44.02	7	1	.00	3	4				
46.83	10	1	.96	2	2d	.83	Cb	10	4
47	--	--	.76	--	2				
50.14	2	--							
53.27	2	--							
53.78	6	--				.83	Cb	3	--
58.94	1d	--							
62	--	--	.70	3	3d				
65.94	25	3	.93	5	5				
70.70	1	10	.62	2	3				
73.79	4	6	.78	4	4				
86.25	3	3	.24	--	3				
97.93	4	1	.94	3	3				
98.86	50	4	.86	6	6				
4599.46	2	10				.45	Cb	1	2
4602.71	4+p	3							
05.78	5	4	.76	3	4				
08.10	10	2	.10	4	4				
13.72	3	10?	.71	3	3				
14.20	3	--							
19.52	2	--	.46	2	2	.51	Ta	4	2
20.87	30	3	.85	6	5				
22.71	8	15	.70	4½	5				
28.19	2	--							
30.62	5	?							
40.13	3	4							
42.25	7	--	.25	4	3				
47.45	1	--				.44	Fe	4	2
48.32	2	--	.35	--	2d				
50.58	3	--	.62	2	3d				
52.25	2	--	.09	2d	3d				
55.19	40	3	.19	6	5				
59.20	2	2	.29	--	2				
60.21	1	--							
64.13	20	25	.14	5½	5½				
69.22	2	--	.25	2	2				
70.91	2	--	.94	--	2				
82.66	1?	4							
83.94	3	--							
86.38	2	--							
88.39	6	1							
95.98	1	--							
99.01	15	2	.02	4	4½				
4699.72	4	8	.70	3	4				
4703.11	10nl	--							
03.61	1+p	3							
08.86	2	--	.85	3	3				
12.20	1+p	--							
14.98	--	2							
19.10	8	8				.11	Zr	6	5

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
21.70	5	1	0.74	3	3				
29.10	1p?	--							
31.36	4	9							
35.67	5c	--	.62	3	3d				
37.66	2po	--							
38.13	2	--							
38.59	8	1	.61	3	3				
39.82	3	--							
46.72	1	--							
51.53	1d	--							
57.61	6	1	.60	3	3				
60.58	1	5	.53	2	3				
65.77	1	5	.80	2	3				
66.51	15	2	.51	4	4½				
69.36	2	--							
73.72	10	2	.73	4	4				
74.90	5	1	.90	3	3				
77.20	2	--	.16	1	2d				
82.75	40	3	.77	4	5				
87.33	1	--							
90.72	5	8	.72	3	4½				
4795.96	2	--	.98	2	2				
4800.50	70	8	.51	6	6				
07.14	3	4	.14	2	3				
09.18	2	3	.24	2	2				
11.14	3	1	.14	2	3				
13	--	--	.86	1	2				
17.22	5	12	.20	3	4½				
18.84	15	2	.86	4	4				
20.29	--	2							
34.20	10	1	.20	4½	3				
37.24	20	2	.26	5	5				
43.99	3	4	4.00	3	3				
47.44	2	--							
48.45	3	6	.50	2	3				
50.58	5	--	.64	3	3				
58.41	8	1	.45	3	4				
59.23	30	2	.26	4½	5½				
60	--	--	.60	1	1				
61.49	2	--	.54	2	1				
63.27	20	2	.31	4	5				
65.41	2	5th	.46	2	3				
72.94	5	1	.97	3	3				
77.58	20	2	.61	4½	5				
78.15	3	--	.16 (Ca)	3	3	.17	Ca	10	8
85.73	1	2							
86.32	2c	--							
88.07	2c	--							
89.57	2	--				.61	Cb		2
89.89	2	--	.79	2d	1d				
94.46	1	2							
4896.32	3	--	.36	3	3				
4903.04	2	--	.02	2d	3	(.04	Ru	15	3)
04.49	5	10	.44	3	4	{.49	Zr	3	
						(.49	Cb	5	
06.33	3c	--	.29	1d	1d				
07.28	2c	--	.20	2d	1				
10.09	3	--	.05	2	2				
10.93	3	--							
15.28	5	--	.24	4	3				
20.96	2	4	.88	2	2	(.97	La	8	5)
26.14	2c	--							
26.95	2	2							
28.37	1	4							
33	--	--	.88	1to	4				
34.44	9	10	.34	4½	4½				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
38.32	1	2				
43.40	1	--				
45.36	4	3	.32	4	3	
47	--	--	.34	2	1	
48.94	8	1				
62.37	5	1				
65.35	2d	--	.30	2	2	
69	--	--	.26	2	1	
69.87	1	--				
75.25	25	3	.22	6	5	
76	--	--	.94	2	2	
84.75	1	2	.68	2	2	
92.36	2d	--	.28	3	2	
4999.68	5	5	.61 (Ti)	5	4	
5000.54	2	--	.58	2	2	
03.39	1d	--				
05.12	1	--				
12.19	1	--				
18.20	20	2	.14	6	4½	
21.11	4	--	.09	3	2	
21.75	4	--				
23.07	4	--				
25.91	2	--	.80	2	2	
34.33	2	4				
34.90	3	--				
37.33	1	--	.32	2	1d	
37.78	1	--				
40.21	1	--				
40.82	15	30	.79	6	6	
45	--	--	.28	1	1	
47.45	15	5	.43	5	4	
51.32	3	--	.31	2	1	
57.03	2	6				
58.16	2	5	.09	3	2	
60.58	1	--				
63	--	--	.12	1	--	
69.80	2	--				
71.21	2	6	.18	2	1	
72.29	1	--				
74.71	20nl	--	.71 B. H.	3	3	
75.91	4	10	.90	2	2	.96 Cb 4
79.63	8	30	.57 B. H.?	3	3d	
80.44	1	6				
90	--	--	.86	2		
93.88	5	--	.84 B. H.	4	2	
5098	--	--	.20 B. H.?	1		
5100.67	3	--	.68	2		
01.68	2	--	.64	2		
06.	--	--	.55	2		
09.66	2	--				
10.58	--	5				
11.33	1p?	--	.28	1		
12.13	6	1				
13.57	4	--				
14	--	--	.36	1		.37 Pd 8 --
18.46	2	--				
19.78	1p?	--				
28.52	4	12	.50	4	2d	
28.93	--	1				
31	--	--	.56	1d		
33.87	2p?	--				
36.19	1	--				
47.57	1	--				
53.12	3	--	.16	3	1	
54.64	2d	--				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
56.05	--	4							
57.96	12	10							
61.57	1	--							
62.06	1	--							
64.43	4c	--							
64.55	1	6							
66.38	2	--							
67.42	3	--				.44	Cb	1	
70.18	10	5	.23	4½	2				
73.16	1	--				.15	Mo	9	2
76.09	1p?	--	.17	1					
81.86	25	10	.93	6	3				
82.87	1c	--							
84.29	2	--							
86.84	4	--							
87.73	4	15	.76	4	2				
94.55	1	3	.57	2					
5199.54	1	--							
5200.87	2	--							
05.10	1	--							
08	--	--	.86	3		.90	Pd	10	
22.46	1	--							
35.12	2	--							
40.40	1	--							
43.99	15	2	.97	5½	2				
44.68	2	--	.60	3					
47.10	6	?	.07	4	2				
47.14	?	30							
54.49	2	--	.38	2d					
55.44	1	--							
58.75	2	--	.75	2					
60.43	4	15	.41	4	2				
64.95	6	20	.92	4½	3				
69.92	1	--							
75.04	7	1	.35	4	1	.02	Ta	5	
76.36	--	1							
84.60	1	--	.63	1					
86.09	4	--	.10	3					
89.96	--	5	.94	1					
90.23	1	--							
90.80	2	--	.79	1					
92.78	2	--	.77	2d					
94.87	12	2							
98.06	10	30	.05	6	3				
5299.84	2	6	.86	2d					
5304.19	2	--	.18	2					
07.82	4	--	.83 (Zr)	3					
09.68	6	1	.67 (Zr)	4	1				
11.60	10	25	.55	6	4				
24.25	3	6	.29 (Fe)	4	2				
46.29	3	15	.31	3	2				
48.39	2	5	.45	3	1				
54.73	12	2	.75	6	2				
58.33	2	--	.35	2					
60.75	2h	--							
61.33	--	1e	.42	1					
68.50	1	--	.56	1					
71.12	2	--	.03	1d					
71.78	1	2							
73.86	15	3	.89	6	3				
83.04	3	--	.07	2					
89.33	6	1	.40	4½	1				
91.35	2	5	.33	2d	1				
94.89	2	--							
5398.64	1	--	.71	1d					

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes			
	Arc	Spark		Arc	Spark				
5402.50	3	--				.53	Ta	5	3
04.47	4	--	.47	4	1				
11.25	1	--							
24.00	3	--	3.99 (Fe)	3	1				
28.30	1	--							
30.05	--	2e							
35.78	3	--	.79	2					
38.74	5	--	.78	4½	2				
44.06	3	10	.05	4	2				
52.92	8	2	.90	5½	2				
63.36	?	10?	.33	6	3				
93.22	--	3e							
5497.30	3	--	.26	3	1				
5503.28	1	--	.18	1					
10.12	3	--	.12	3					
10.44	3	--	.42	3	2				
15.00	--	1e							
17.33	1	--							
18.47	1	--							
20.00	1	--							
22.55	1	--							
24.35	5	15	.39	4	3				
24.96	1	--	.92	1		(.93	Co	7	)
30.29	2	--	.30	2					
38.02	4	1	.09	4d	1				
38.26	3	--							
38.59	2	--							
41.91	1	1	.95	1					
47.83	--	1e							
50.60	30	5	.60	6	4				
52.12	40	5	.12	6	4				
75.86	6	5	.87	4½	2				
5590.70	--	1e	.75	2	1	(.73	Co	8	1)
5600.77	2	--	.82	2					
13.27	10	3	.31	5½	3				
14.01	3	--	3.99	3					
28.27	2	--	.21	2		.24	Cb	3	
31.34	--	2e							
33.48	1	--							
36.61	--	1e							
44.69	1	--	.52	1		(.69	Y	4	1)
50.83	3	--	.74	3	1				
54.64	4	--	.56	3	1				
60.40	--	1e							
62.08	2	--	.08 (Ti)	2					
63.01	1	--	2.97	1					
64.33	--	1e							
68.72	1	1							
73.58	1	5	.60	1	1				
89.77	--	1e							
5698.04	10nl	--	.10 B. H.	4	2				
5702.09	1	--							
13.28	4	1	.28	4	2				
19.18	40	10	.22	6	4				
20.14	3nl	--	.14 B. H.	3					
34.54	3	--	.61	3	1				
42.52	2	--	.65	1d	1				
48.72	4	1	.73	3	2				
52.53	--	2e							
56.78	1p?	--							
61.14	1p?	--							
62.02	1p?	--							
65.38	2	--	.33	2d	2d				
65.57	1p?	--							
65.99	2	--	.98	2					

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
67.19	3	10	.18	3	2	
88.08	2	--	.13	1		
96	--	--	.28	1		
5799.78	2	--	.72	1		
5801.71	2	4				
02.90	1	--				
07.17	1	--	.19	1		(.18 V 5 2)
08.42	2	--	.39	1		
09.51	3	5	.52	3		
11.26	1	--	.26	1		
17.47	3	--	.45	2	1	
38.87	2	--	.89	2		
42.23	5	15	.24	4½	1	
45.87	4	--	.88	3		
47.77	3	--	.76	2		
49.70	3	--				(.73 Mo 8 5)
58.35	2	--				
83.66	3	--	.68	3	1	
86.32	1	--	.30	1		
87.44	1	--				
90.45	8	--	.50	4		
96.61	2	--				
5898.24	--	1e				
5902.94	15	3	.93	6	3	
26.47	2	--	.52	2		
33.69	6	1	.74	4	3	
38.12	1	--				
69.40	1	2				
74.28	10	2	.31	4½	3	
74.72	2	--				
78.66	6	1	.67 (Ti)	4	2	
86.62	1	--	.49	1d	1d	.62 Cb 2
92.96	2	--	.99	2	1	
5994.59	1	--				
6016.79	4	1	.78 (Mn)	3	2	
21.14	3nl	--				
27.57	2	5				
31.94	[1] a. c. --	a. e. 2				
41.46	--	3				
43.19	2c	--	.22	3d	1	
48.00	--	3				
54.17	2	--	.09	2d	1	
93.15	--	2				(.14 Co 6 2)
97.47	--	2				
6098.67	5	1	.67	4½	2	.70 Ti 5 3
6118.16	2	--	.20	2	1	
35.10	1	5	.13	1		
56.28	--	2d?				
58.74	--	2				
60.70	--	2				.7 L — 1
85.13	5	6	.13	5		
6192.50	1	2	.46	1		
6202.85	--	1	.78	1		
06.96	--	2				
09.42	1	1?	.45	2		
10.70	3	4	.72	3		
11	--	--	.92	1		
16.82	1	3	.78	3		
22.80	1	4				
29.65	--	2				

[1] a. c.=arc center; a. e.=arc electrode.

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
30.84	2	15				
38.58	3	4	.49	3		
48.96	5	20	.90	4		
57.00	2	6				
58.81	2	4				
71.09	--	3				
79.85	2	15				
91.48	1	2d?				
6299.54	2	5				
6306.19	1	5				
08.67	1	2				
10.75	1	2				
11.85	3	6	.76	2		
13.46	2	3				
15.94	1	5				
18.33	3	5	.36	1		
28.86	1	2				
34.55	1	2				
37.76	--	1				
38.10	4	7	.14	3		
40.71	1	2				
43.76	--	4				
47.62	1	2				
49.86	1	1				
57.36	1	2				
59.83	1	2				
74.60	1	2				
76.20	1	3				
80.19	3	6				
83.75	1	2				
86.23	15	20	.34	5		
88.20	1	2				
88.91	1	2				
90.30	1	2				
6391.00	1	2				
6409.52	3	5	.54	2		
29.49	1	2				
31	--	--	.8	2		
44.98	1	2				
48.43	1	2				
49	--	--	.9	2		.81 Ca 5 3
55.87	1	4				
56.97	4	8	7.0	2		
62.31	1	4				
71	--	--	.5	1		.68 Ca 5 5
73.92	2	6				
78	--	--	.7	1		
82.57	1	2				
86	--	--	.5	2		
6494.60	1	3				
6511.63	--	4				
12.63	--	6				
23.94	1	2				
26.22	1	4				
31.68	1	5				
36.56	1	2				
37.06	1	2				
41.01	1	2	.2	1		
42.81	1	6				
46.02	1	2				
48.25	1	3				
50.02	1	3				
52.92	1	2				
55.98	1	2				
56.50	4	8	.6	2		

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
57.00	1	1				
57.93	3	15	8.0	3		
65.77	--	3				
67.41	2	12	.5	2		
81.15	1	1				
84.55	2	10	.6	1		
87.23	5	10	.2	4		
6599.77	--	2				
6605.91	--	1				
09.22	--	4				
16.14	1	2				
24	--	--	.4	2		
28	--	--	.1	1d		
31	--	--	.5	1d		
35.38	1	2				
44.60	10	40	.6	6		
47.05	5	20	.0	4		
56	--	--	.7	2d		
59.40	1	3	.5	2d		
60.84	2h	10hAg?				
65.08	--	1				
69.31	1	2				
71.29	1	2				
84.48	--	1				
91	--	--	.0	2		
91.67	1	2				
6693.49	--	1				
6708.33	--	2				
09.41	1	6				
13.48	4	8	.5	4		
16.00	1	3				
34	--	--	.7	2		
47	--	--	.6	3		
54.62	5	15	.6	5		
69.95	2	4				
73.07	1	3				
6789.27	10	20	.3	6		
6803	--	--	.0	1		
18.94	20	40	9.0	6		
26.56	2	5	.6	3		
33.77	1	2				
36	--	--	.4	1		
50.07	1	4	49.9	1		
55.29	1	4				
57.00	1	2				
58.70	3	15	.6	3		
6874.95	1	2d				
6906	--	--	.3	1		
11.40	3	10	.3	3		
26.19	1	3				
35.17	1	3	.2	1		
37	--	--	.1	1		
65.80	1	3				.85 L 1
70.44	--	2				
76.18	--	1				
79.59	1	4	.6	2		
80.90	3	25	.8	4		
81.60	1	2				
6997.81	--	3				
7010.68	--	2				
16.99	--	2				
19.25	--	2				
21.21	--	3				
30.32	2	10	.3	2		
35.13	1	2				

TABLE 1.—*Arc and spark spectra of hafnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
52. 62	--	1				
54. 06	--	2				(.05 Co 8 ---)
61. 88	--	2				
62. 87	1	3				
63. 83	8	20	.7	5		
7094. 40	1	3				
7100. 54	1	3				
15. 65	--	1				
19. 52	3	10	.5	2		
31. 81	30	50	.8	6		
7164. 54	--	2				
7237. 10	20	40	.2	5		
40. 87	15	30	.9	5		
62. 62	1					
77. 68	2	3				
7278. 76	--	1				
7320. 05	3	5				
21. 76	1	2				
28. 61	1	2				
46. 82	3?	--				
56. 10	2					
65. 28	2					
90. 70	1	2				
7398. 99	--	1				
7409. 38	1h					.35 Ni 9
23. 69	1	3				
37. 56	1	4				
42. 33	1	3				
63. 86	2					
7484. 56	1					
7556. 37	2					
62. 93	8					
64. 22	2					
76. 95	2					
7592. 96	2					
7605. 78	1					
08. 59	2					
24. 40	30					
7645. 64	2					
7708. 36	2					
40. 17	10					
43. 58	1					
57. 87	1					.8 Rb 6
7790. 90	5					.91 Mn 2
7814. 55	3					
7845. 35	20					
7920. 71	8					
38. 06	2					
71. 56	1					
76. 84	1					
86. 91	1					
7994. 73	20					
8010. 58	2					
46. 03	3					
56. 52	4					
59. 10	3					
8080. 32	4					
8143. 60	1					
73. 89	5					
74. 89	1					
93. 74	1					
8194. 78	8					
8204. 58	20					
16. 32	3					
36. 15	2					

TABLE 1.—*Arc and spark spectra of halfnium*—Continued

λ I. A.	Intensity		λ Hansen and Werner	Intensity		Notes
	Arc	Spark		Arc	Spark	
44. 37	1					
48. 81	3					
8276. 95	20					
8338. 12	2					
44. 25	8					
61. 78	4					
82. 98	2					
84. 94	1					
8399. 97	1					
8451. 73	1					
54. 11	1					
60. 01	10					
75. 35	1					
8497. 49	1					
8508. 11	1					
46. 48	20					
69. 0	3d					
84. 12	5h					
8592. 23	1					
8603. 24	2					
29. 43	1					
40. 06	15					
58. 41	1d					
61. 88	2					
8673. 90	1					
8711. 24	7					
8715. 62	2					
8825. 30	1					
8836. 16	3					
9004. 73	3					
9182. 07	2					
9193. 23	1					
9250. 27	3					

[18] Hansen and Werner, see reference 4. Hevesy, see reference 5.

[19] Exner and Haschek, Die Spektren der Elemente bei Normalen Druck, **II**, p. 341; 1911; and **III**, p. 324; 1912.

[20] Kiess, B. S. Sci. Papers (548), **22**, p. 47; 1927; and unpublished data.

[21] Bachem, Diss. Bonn; 1910.

[22] Vahle, Zeitschr. Wiss. Phot., **18**, p. 84; 1918.

IV. DISCUSSION

1. COMPARISON WITH ZIRCONIUM SPECTRA

The statement has frequently been made that all zirconium minerals contain appreciable amounts of hafnium and that consequently all the samples of zirconium salts and metals which have been used heretofore for the description of zirconium spectra contained hafnium as an unrecognized impurity.[18] The truth of this statement is attested by Table 2 in which faint lines observed in zirconium spectra by various observers are identified with the stronger lines of hafnium as determined in the present investigation. Comparison is made with the measurements of zirconium spectra by Exner and Haschek,[19] by Kiess,[20] by Bachem,[21] and by Vahle.[22] In addition to proving that strong hafnium lines have been observed

faintly in zirconium spectra this comparison supports, in general, my differentiation of arc and spark lines, and gives furthermore an indication of the accuracy of my wave-length values.

Practically all of the stronger lines of hafnium not obscured by true zirconium lines are to be found in the zirconium lists of Exner and Haschek, and, in general, my spark lines appear most prominently in their spark spectrum table, while my arc lines have a tendency to show only in their arc spectrum table, except in the region of wave lengths greater than 3400 A where it appears that their arc exposures were relatively much weaker than their spark exposures.

Kiess, before publishing, compared his zirconium measurements with Hansen and Werner's hafnium list and with a portion of mine which was completed a year ago, and was thus able to remove most of the hafnium lines as impurities. The data presented in Table 2 are mainly from his unexpurgated lists which cover 2200 A to 6100 A in the spark and 4900 A to 9300 A in the arc spectrum.

Bachem and Vahle each measured the arc spectrum of zirconium with a large concave diffraction grating and each strove to obtain values so that the probable errors would be less than 0.01 A. As mentioned above, the values by Bachem in certain spectral regions have errors of scale several times this amount, and the values in Table 2 have, therefore, been corrected to the scale of Vahle's observations. The agreement between these accurately measured faint lines in their zirconium spectra and the stronger lines in my hafnium list is remarkably good. The difference for 20 lines is 0.00 A, for 16 lines it is ±0.01 A, for 4 lines ±0.02 A, and for one line 0.03 A.

The + sign after an Exner and Haschek intensity number means "not sharp"; the notation s after Vahle's intensity number signifies "weak," and ss, "very weak."

TABLE 2.—*Hafnium lines observed in zirconium spectra*

Meggers			Exner and Haschek			Kiess			Bachem		Vahle	
λ	Intensity		λ	Intensity		λ	Intensity		λ	arc	λ	arc
	Arc	Spark		Arc	Spark		Arc	Spark				
2277.15	10	10	.19	--	1	.17		2	.165	1		
2310.21	--	10	--	--	--	.23		1				
13.42	1	30	.45	--	1	--		--				
19.06	1	8	--	--	--	.06		1				
22.46	10	15	.50	--	2	.47		2	.461	1		
36.47	1	50	.50	--	1+	.50		3				
47.45	8	25	.42	--	1	.45		1				
51.22	10	30	.20	--	1	.21		2				
55.49	--	20		--	--	.50		1				
77.57	--	20		--	--	.61		1				
80.29	5	10	.3	--	1+	.31		1				
83.55	1	30	.54	--	1	.56		2				
93.36	5	10	.3	--	1+			--				
2393.83	10	20	.82	--	1			--	.824	1		
2405.43	10	25	.43	--	1			--				

TABLE 2.—*Hafnium lines observed in zirconium spectra*

Meggers			Exner and Haschek			Kiess			Bachem		Vahle	
λ	Intensity		λ	Intensity		λ	Intensity		λ	arc	λ	arc
	Arc	Spark		Arc	Spark		Arc	Spark				
10.13	8	15	.13	--	1	.14		1				
17.69	8	15	.70	--	1	.68		1				
33.56	5	15	.55	--	1	.56		1				
47.25	10	20	.22	--	1	.24		1				
60.50	15	40	.53	--	1	.47		1				
64.19	20	75	.22	--	1	.15		1				
69.18	8	20	.22	--	1+			--				
2495.17	1	80		--	--	.12		1				
2512.68	15	30	.72	--	1	.65		1				
13.02	25	50	.06	--	1	.01		1				
15.16	--	30		--	--	.14		1				
16.88	25	100	.91	--	1	.86		1	.866	1		
31.20	10	25		--	--	.20		1				
51.40	10	50	.41	--	1	.39		1				
73.92	8	40	.94	--	1			--				
76.84	7	20		--	--	.84		1				
2582.51	5	15		--	--	.51		1				
2606.38	8	20	.34	--	1	.38		1				
07.04	10	30	6.99	--	1			--				
13.61	7	20	.61	--	1			--				
22.75	5	20	.76	--	1	.75		1				
38.72	10	30	.68	--	1	.70		1	.720	1	.718	1ss
41.42	10	50	.38	--	2	.40		2	.408	1		
47.31	8	30	.24	--	2	.29		1	.284	1		
61.89	4	12	.88	--	1	.95		1				
65.98	2	6		--	--	6.01		1				
2683.36	5	20	.36	--	1	.36		1				
2738.76	10	25	.74	--	1	.76		1	.759	1		
73.37	20	50	.37	--	1	.35		3	.362	1	.360	1s
89.51	1	8		--	--	.47		1				
2789.74	4	20	.75	--	1	.73		1				
2814.47	3	10		--	--	.45		1				
20.23	20	50	.22	1	1	.22		2			.232	1ss
22.67	10	25	.68	--	1			--				
49.21	5	25	.19	--	1+	.17		1				
61.01	10	20	.0	--	1+			--	.013	1		
61.69	15	30	.72	1	1	.68		2	.700	1	.707	1s
66.38	20	3	.39	1	--			--	.378	1	.378	1s
76.33	4	20		--	--	.30		1				
98.26	25	3	.29	1	--			--			.259	1
2898.71	3	12	.74	--	1	.72		4ZrII	.712	2	.715	2
2904.42	20	3	.43	1	--			--	.409	1	.419	1
04.76	20	2	.79	1	--			--	.754	1	.762	1ss
16.49	30	5	.49	1	--			--	.479	1	.488	1
19.59	10	20		--	--	.56		1				
29.63	10	10	.59	1	--			--	.630	1	.617	1ss
29.90	8	1		--	--			--			.923	1s
37.80	10	30	.77	--	1			--				
40.77	25	4	.74	1	--			--	.755	1	.773	1ss
50.68	20	3	.68	1	--			--	.680	1		
54.21	15	2	.22	1	--			--				
64.88	20	3	.87	1	--			--	.873	1		
75.90	12	30	.88	1	1	.86		1				
2980.82	15	2	.85	1	--			--	.810	1		
3012.90	15	25	.89	1	--	.88		1				
16.78	30d?	2	.78	1+	--			--				
18.32	15	2	.28	1+	--			--				
50.76	10	2	.79	1	--			--				
57.02	20	3	.03	1	--			--				
64.68	2	8	.66	--	1			--				

TABLE 2.—*Hafnium lines observed in zirconium spectra*

Meggers			Exner and Hoschek			Kiess			Bachem		Vahle	
λ	Intensity		λ	Intensity		λ	Intensity		λ	arc	λ	arc
	Arc	Spark		Arc	Spark		Arc	Spark				
3072.88	30	4	.93	1	--			--			.881	1
3101.38	8	15		--	--	.36		1				
09.11	15	40	.14	1	1	.11		1				
34.72	25	40	.72	1	1	.72		1				
76.86	10	20	.87	--	1			--				
3194.20	15	25	.14	--	1	.20		1				
3220.66	3	10	.67	--	1			--				
53.70	15	25	.68	--	1	.68		1				
3255.29	6	8	.3	--	1+			--				
3312.87	15	3	.88	--	1			--				
32.73	20	2	.75	1	1			--				
52.06	10	20	.07	--	1	.02		1				
89.83	10	15	.81	--	1			--				
3399.80	30	40	.80	1	2	.80		2	.776	2		
3472.38	20	2	.38	--	1			--				
3505.23	20	40		--	--			--	.227	1		
35.54	10	20	.52	--	2			--				
36.62	10	1	.6	--	1+			--				
52.70	10	15	.76	--	1			--				
61.65	20	25	.66	--	2	.66		1				
3569.03	20	30	.03	--	1	.05		1				
3616.89	10	2	.87	--	1			--				
44.35	15	20	.39	--	2	.36		1				
65.36	4	10	.36	--	1			--				
75.74	9	2	.75	--	1			--				
3699.73	7	15	.75	--	1			--				
3701.15	8	25	.15	--	2	.15		1				
05.41	3	8	.43	--	1			--				
17.80	15	3	.79	--	1			--				
19.27	15	25	.30	--	1	.28		1				
33.78	10	2	.78	--	1			--				
44.98	3	10	5.01	--	1			--				
62.51	2	20	.55	--	1			--			.511	1s
66.93	4	25		--	--			--			.952	1ss
77.64	30	4	.67	--	1			--				
3793.37	20	20	.38	--	2			--				
3806.07	4	25		--	--	.06		1				
3899.93	12	2	.93	--	1							
3918.10	15	10	.10	--	1							
23.91	6	10	.90	--	2							
31.36	8	2	.40	--	1+							
51.81	15	2	.81	--	1							
64.95	3	7	.92	--	1							
79.40	1	12	.35	--	1+							
84.03	1	4	.00	--	1							
3996.80	1	3	.83	--	1							
4047.96	2	15	8.00	--	1+							
80.44	10	10	.49	--	1							
4093.17	40	25	.17	1	2				.157	1	.162	1ss
4158.90	2	10	.94	--	1							
62.40	4	15	.44	--	1							
74.33	30	3	.40	--	1							
4177.50	3	15	.59	--	1+							
4232.46	6	20	.48	--	1							
49.33	5	9	.39	--	1+							
4272.84	7	15	.91	--	1							
4320.67	6	10	.7	--	1+							
34.64	3	8	.7	--	1+							
36.65	10	40	.70	--	1+							
50.50	8	25	.54	--	1							

TABLE 2.—*Hafnium lines observed in zirconium spectra*—Continued

Meggers			Exner and Haschek			Kiess			Bachem	Vahle
λ	Intensity		λ	Intensity		λ	Intensity		λ arc	λ arc
	Arc	Spark		Arc	Spark		Arc	Spark		
4367.89	8	6	.9	--	1+					
4417.35	8	10	.4	--	2+					
22.75	6	30	.80	--	1					
4438.02	10	2	.04	3	2					
4533.18	12	6	.2	--	1+					
70.70	1	10	.7	--	1+					
4598.86	50	4	.82	1+	--					
4622.71	8	15	.72	--	1					
4640.13	3	4	.13	2	1					
4782.75	40	3	.68	1	--					
4800.50	70	8	.57	1+	--					
7131.81	30					.84	3			
7237.10	20					.08	3			
7240.87	15					.88	3			
7562.93	8					.94	1			
7624.40	30					.48	2			
7740.17	10					.13	2			
7845.35	20					.34	2			
7994.73	20					.75	1			
8460.01	10					.04	1			
8546.48	20					.48	1			

2. COMPARISON WITH SOLAR SPECTRUM

It appears that a considerable number of the stronger lines of hafnium in Table 1 are identifiable with faint Fraunhofer lines in the sun's spectrum. Unfortunately, no comparisons can be made in the region short of 3000 A where many of the strongest hafnium lines occur, and in the spectrum above 3000 A recognition of certain hafnium lines in the sun is prevented by approximate coincidences with strong lines of iron, cobalt, nickel, titanium, chromium, calcium, etc. The best coincidences are displayed in Table 3 in which Rowland's [23] wave lengths of Fraunhofer lines and the corrected international values appear in column 1, Rowland's intensities in column 2, followed by my hafnium wave lengths and intensities in columns 3 and 4. A question mark in the last column indicates that the identification is doubtful, either on account of discordant wave length or intensity. The latter applies especially to arc lines. Since the strongest are not recorded in the sun the coincidence of weaker arc lines with Fraunhofer lines is probably accidental. Coincidences occur, for the most part, only with the faintest lines observable in the solar spectrum, OOO or OOOO on Rowland's scale of intensities. Occasional coincidences with intensity 1 lines are probably accidental or blends. This appearance of hafnium in the solar vapors might have been deduced from the behavior of its chemical analogues, titanium and zirconium. The former is rather conspicuous in the

[23] Rowland, Solar Spectrum Wave Lengths; 1896.

solar spectrum while the latter is much less prominent, and hafnium being still heavier could be expected to be represented only by the faintest lines, if at all. In each case the lines from ionized atoms are stronger on the average than those from neutral atoms.

TABLE 3.—*Identification of hafnium lines in the solar spectrum*

Sun {R / I. A.}	Intensity	Hf I. A.	Intensity			Sun {R / I. A.}	Intensity	Hf I. A.	Intensity		
			Arc	Spark					Arc	Spark	
3057.117	OON	3057.02	20	3	?	3733.910	OO	3733.78	10	2	?
.011						.770					
3131.920	OOO	3131.81	12	2	?	3738.026	OO	3737.88	4	10	
.814						7.886					
3134.830	OO	3134.72	25	40		3877.232	OO	3877.11	3	20	
.724						.092					
3159.945	OON	3159.83	10	1	?	3900.797	OOO	3900.66	1	10	
.837						.657					
3176.946	OOO	3176.86	10	20		3924.065	OOO	3923.91	6	10	
.836						3.925					
3193.661	OOON	3193.53	10	15		4080.588	OO	4080.44	10	10	
.543						.433					
3194.346	OO	3194.20	15	25		4083.515	OOO	4083.36	10	2	?
.228						.360					
3253.841	OOOO	3253.70	15	25		4174.479	OO	4174.33	30	3	?
.715						.316					
3255.413	OOO	3255.29	6	8		4206.735	1	4206.57	5	20	?
.287						.575					
3332.850	OOOO	3332.73	20	2	?	4232.618	OO	4232.46	6	20	
.724						.459					
3389.960	OOOO	3389.83	10	15		4336.774	OON	4336.65	10	40	?
.820						.612					
3399.942	ON	3399.80	30	40							
.802						4418.044	OOO	4417.90	8	1	?
						7.883					
3505.371	OOOO	3505.23	20	40		4422.872	OOO	4422.75	6	30	?
.230						.711					
3535.660	OOOO	3535.54	10	20							
.519						4438.192	OO	4438.02	10	2	?
3561.796	OOOO	3561.65	20	25		.029					
.655						4599.618	OOOO	4599.46	2	10	
						.444					
3617.016	OOOON	3616.89	10	2	?						
6.876						4773.900	OOOO	4773.72	10	2	?
3644.455	OOOON	3644.35	15	20	?	.716					
.315						5576.079	OOOO	5575.86	6	5	?
3661.176	OOON	3661.05	3	8		5.862					
.036											
3699.877	OOO	3699.73	7	15							
.737											
3705.561	OON	3705.41	3	10							
.421											
3719.405	OOOO	3719.27	15	25							
.265											

3. PERSISTENT LINES OF HAFNIUM

The preceding identifications of hafnium lines in zirconium spectra, and in the solar spectrum, perhaps, give some indication as to which hafnium lines are sensitive in revealing the element as a spectroscopic impurity. From the above tables a dozen arc lines and the same number of spark lines have been selected as representative of the persistent lines of hafnium. They are collected in Table 4. The *raie ultime* can not be established with certainty, but it appears very probable that 4093.17 A plays this rôle for neutral hafnium

atoms and 2773.37 A for ionized atoms. An attempt to establish the persistent lines of hafnium has been made by Petersen,[24] who examined the arc spectra of zirconium ores and oxides in a limited spectral range (2500 A to 3500 A). He found the lines at 2773.37 A, 2866.38 A, and 2919.59 A to be most persistent, while 2516.88 A, 2887.13 A, 2898.26 A, 2904.42 A, 2964.88 A, and 3194.20 A were slightly less persistent. While some of these lines are true spark lines, others are undoubtedly arc lines. The spark line 2773.37 A was selected as the most persistent. It is of interest to note that the line at 4093.17 A is the only hafnium line identifiable with lines observed 30 years ago in the arc spectrum of zirconium by Rowland and Harrison.[25] They reported a line of intensity 2 at 4093.16 A. The fact that this line is not recorded in the solar spectrum makes the recognition of neutral hafnium in the sun very doubtful.

TABLE 4.—*Persistent lines in hafnium spectra*

λ	Hf I intensity		λ	Hf II intensity	
	Arc	Spark		Arc	Spark
2898.26	25	3	2512.68	15	30
2904.42	20	3	2513.02	25	50
2904.76	20	2	2516.88	25	100
2916.49	30	5	2773.37	20	50
2940.77	25	4	2820.23	20	50
2950.68	20	3	3134.72	25	40
2964.88	20	3	3194.20	15	25
3072.88	30	4	3399.80	30	40
3332.73	20	2	3505.23	20	40
3777.64	30	4	3561.65	20	25
4093.17	40	25	3569.03	20	30
4174.33	30	3	3719.27	15	25

A very excellent method of arriving at the true *raie ultime* of a spectrum is through an analysis of the structure of the spectrum and classification of its lines. No spectral regularities have been announced for hafnium spectra, but such are now being sought in a list of vacuum wave numbers derived from the wave lengths in Table 1.

In conclusion, the author wishes to express his appreciation for the assistance in thousands of wave-length calculations carefully performed by Bourdon Scribner in this laboratory.

WASHINGTON, March 21, 1928.

[24] Petersen, Nature, **119**, p. 352; 1927.
[25] Rowland and Harrison, Astrophys. J., **7**, p. 373; 1898.